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## Galactic neutrino communication

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## ARTICLE INFO

## Article history:

Received 21 August 2008

Received in revised form 15 November 2008

Accepted 18 November 2008

Available online 27 November 2008

Editor: A. Ringwald

## PACS:

95.85.Ry

98.70.Sa

84.40.Ua

## ABSTRACT

We examine the possibility to employ neutrinos to communicate within the galaxy. We discuss various issues associated with transmission and reception, and suggest that the resonant neutrino energy near 6.3 PeV may be most appropriate. In one scheme we propose to make  $Z^0$  particles in an overtaking  $e^+ - e^-$  collider such that the resulting decay neutrinos are near the  $W^-$  resonance on electrons in the laboratory. Information is encoded via time structure of the beam. In another scheme we propose to use a 30 PeV pion accelerator to create neutrino or anti-neutrino beams. The latter encodes information via the beam CP state as well as timing. Moreover the latter beam requires far less power, and can be accomplished with presently foreseeable technology. Such signals from an advanced civilization, should they exist, will be eminently detectable in existing neutrino detectors.

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## 1. Introduction: Neutrinos for galactic communication

The search for extraterrestrial intelligence (SETI) has now gone on for decades without detecting a signal. Thus far, the search has presumed that the transmission would be in photons within radio or optical bands. In this note, we suggest that it may be more sensible to search for a possible signal in neutrinos. We will discuss some of the physics issues related to both transmission and reception.

Why would one want to employ the notoriously difficult-to-observe neutrino to communicate? Some reasons are obvious.

- (i) The obscuration/opaqueness of material between the source and detector makes photons less useful within the galactic plane and particularly for lines-of-sight anywhere near the galactic center. Neutrinos arrive almost without attenuation from any source direction (though at the energies we suggest below, they are attenuated through the earth).
- (ii) Neutrinos are rare, and from a given direction are all but negligible (particularly at high energies as we discuss below). For photons the signal/noise (S/N) problem is not at all negligible in any band and is worse for all directions where galactic civilizations may reside (presumably in the galactic plane). For neutrinos the band can be essentially noise free.
- (iii) Even when photons are not completely blocked, their scattering introduces jitter in arrival time as well as direction. As we

discuss below, the reasonable encoding for maximally energy-efficient information transfer may employ the time interval between quanta. Moreover, in one scheme, data may be encoded via the use of neutrinos versus anti-neutrinos.

There have been early general proposals for the use of neutrinos for interstellar communication and for SETI [1]. There were also more recent and more specific proposals about the use of neutrinos in SETI [2,3]. In this note we propose a new way of using neutrinos for communication by ETI and point out that existing and future facilities will be able to look for these signals without any need for new construction or expense.

## 2. What neutrino energies are most suitable?

What neutrino energies are best suited for galactic communication?

First, let us consider relatively low energy neutrinos, those typical of nuclear, solar and supernovae (SN) processes. One strike against this energy region, roughly up to around 10 MeV (40 MeV for SN) is that such neutrinos are produced in abundance naturally, so there is some signal-to-noise barrier to overcome. If one thinks of the natural emission from radioactive decays, from stars and from supernovae across the universe, this region is not so attractive since these sources are enormously powerful and one must compete against them. (The “noise” is small, but the inherent signal-to-noise ratio S/N is also small for any imaginable source.) Moreover, directionality at the lower energies is at best difficult. Also, S/N aside, at low energies the neutrino-nucleon interaction cross-section is dauntingly small, of order  $10^{-42}$  cm<sup>2</sup>. (For the same reason of vanishingly small cross-sections, we dismiss further

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discussion of even lower neutrino energies.) We have also considered the possibility of employing resonant nuclear energies, but we have not identified any viable mechanism which will beat the problems of inherent S/N and low cross-sections.

For these reasons we are driven to consider higher energies. The neutrino cross-section grows with energy linearly until the 100 TeV energy range, and then logarithmically. The (dominant) terrestrial neutrino backgrounds fall rapidly, one power in energy more steeply than the cosmic ray spectrum. For a beam, there are further gains of order  $E^2$  due to the solid angle of the beam, and typically one would gain altogether by a factor of  $> E^3$  in signal, and  $> E^6$  in S/N on a per particle basis.

The energy chosen should be such that it would be clear at once that it is an artificial source such as ETI and not some random background. One choice is to make  $Z^0$ 's at rest as was proposed earlier [2]. Then the neutrinos from such a source have energies of exactly  $m_Z/2$ , about 45 GeV, and are easily identifiable as due to  $Z^0$  decay: there are no natural sources of  $\nu$ 's of this precise energy. In this case the neutrinos are emitted in a spherically symmetrical manner, and because of that the power requirements for galactic distances, reach the scale of total solar power (as estimated there) to obtain a significant counting rate. Of course one might argue that this is not "our" problem, but one to be solved by the postulated advanced civilization with technology we cannot yet imagine. But resorting to harnessing (Dyson) stars certainly moves the potentiality of such communication to the distant future, if indeed such is ever practical for a civilization. It was further proposed there that the detection process employed electrons accelerated such that the incoming electron–anti-neutrino interact at the Glashow resonance [4], i.e. producing a  $W$  boson on-shell (an electron energy  $E_e = m_W^2/4m_e$ , about 35.5 GeV) with a large cross-section.

We presume that the ETIs, though in our galaxy, are remote. Even if an ETI has been observing us, it may be a long while (timescale of thousands of years) before they would send us an introductory message. So if they want to send a message in advance, saying hello and welcome to the galactic network, they are going to have to speculate about when to bother to transmit. From the jittering of advances in speciation, with the great die offs, it seems clear that evolution is a stochastic process, with fluctuations on a timescale of many millions of years. The evolution of technology may fluctuate over a timescale of thousands of years, as exemplified by the long periods of lack of technological progress in post-Roman Europe, China and India. One must reason that no useful prediction could be made as to when the industrial revolution would take off and high technology would arise. Thus the ETI would have to be transmitting speculatively over a long period.

Communication may be initiated for many hypothetical reasons. For example, to simply welcome a new society to the galactic club, or to warn of dangers from within or without, or for reasons we cannot now guess. Indeed, it seems best not to speculate on motives for transmission at this point but to focus on physics issues. In any event, it seems that there might be two stages, the first being to simply get the attention of the recipient and the second to send information. One might also imagine ETI sending information to military outposts via secure neutrino beam, on a known schedule and in a small solid angle, and we happen to be in the transmission path, but the probability of our intercepting such is evidently negligible.

Given light transmission time over galactic dimensions, compared to evolution time in our world, we cannot foresee much of a dialogue, but that is of course also true for electromagnetic communication. Note, for example, that signals leaving the center of our galaxy at the time of the first human settlements would not arrive for another 14 millenia. Monologues are what we can anticipate at best. That is the case unless there are means to beat the

speed of light via wormholes or extra dimensions, but such do not now appear to be viable within established physics.

It has been argued persuasively [5] that transmission of large amounts of data via radio or light are very inefficient compared to the deposition of artifacts, snail mail as it were. Artifacts can hold huge amounts of data, and need only be sent once or very seldom to promising star systems and left to be discovered later. We thus imagine that there is not a great need for a high data rate channel in the galaxy, but perhaps only as stated above, for some minimal information of overwhelming importance, which might include instructions on where to find the artifact.

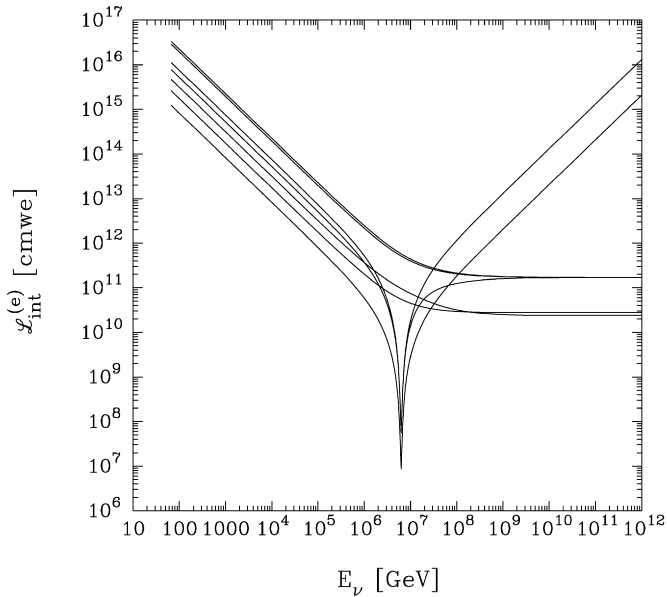
### 3. Directional transmission and detection via resonant neutrinos

Instead of omnidirectional broadcast, let us next consider the possibility of sending out focused neutrino beams in a specified direction, aimed at promising star systems.

Sending out a focused beam has the advantage of not being seen by all, perhaps a worthy security measure. Many have speculated on the danger of attracting unwanted attention by potentially aggressive species (which conceivably could wish to take over a nice proven habitable planet, or even enslave the inhabitants of such a planet – the subject of much science fiction but not obviously a wrong presumption.) Indeed, some have suggested that our civilization should consider measures to keep our galactic visibility to a minimum for just this reason. Hence transmitting to an unknown new society has risks, particularly since with a beam one may reveal the location of the transmitting entities. If this is indeed a real danger, perhaps an advanced civilization would employ a transmitting station, a lighthouse, at some remove from their home. In view of this, perhaps an advanced civilization may be more inclined to transmit to a newly technically emergent society (TES) such as ours. Such action might offer the rewards of heading off more undesirable consequences possible in the longer term, when a TES is not in a position to be too territorially acquisitive. Or perhaps the ETI would simply like to initiate trade as when Europeans first visited China and India. However, our own history gives no precedent in terms of communication prior to contact, and indeed that history is a bit frightening, since first contacts soon led to exploitation.

Let us assume, moreover that the ETI will guess that a civilization ready to hear their messages will have developed to the point of constructing large neutrino detectors in the process of studying neutrinos and attempting to begin neutrino astronomy. It is hard to justify from some future viewpoint, but we see now that a high energy neutrino detector of the scale of 1 km is reasonable (IceCube under construction at the South Pole, and NESTOR, ANTARES and NEMO and an expanded Lake Baikal detector are all proposed or under development[6]). So, for discussion purposes we shall assume the ETI will aim at communicating with a detector of cross-section on the order of  $1 \text{ km}^2$ .

Suppose we make a beam of electron–anti-neutrinos, and get them to a very high energy, to be precise  $E_G = M_W^2/2m_e = 6.3 \text{ PeV}$ . Then these can be sent in some chosen directions to be received by observers who can employ a detector seeking the reaction  $\bar{\nu}_e + e^- \rightarrow W^-$  at resonance, the so-called Glashow resonance, as illustrated in Fig. 1. The production and decay of a  $W^-$  into a shower provides a unique signature; given more than one such event from a given direction the source would be immediately known to be due to an ETI as there are no natural sources of 6.3 PeV  $\bar{\nu}_e$ 's. To contrast with the proposal made in 1994 [2], here we boost the initial beam rather than the electrons in the detector; in both one employs the Glashow resonance and its high cross-section. The range of such a resonant neutrino in water is about 100 km, so that these neutrinos would penetrate to the deepest detectors on earth, but would be attenuated in arrival directions



**Fig. 1.** Electron and muon (and tau same as muon) neutrino and anti-neutrino interaction lengths on target electrons versus neutrino energy, including Glashow resonance. From [7].

below the horizon. This also implies that the detection fraction in a 1 km<sup>3</sup> detector would be about 1% of the traversing neutrinos.

An efficient mechanism for such a beam generation would be to collide electron–positron beams at a center-of-mass energy at the  $Z^0$  mass, but in a fast moving reference frame, so that the decay neutrinos would be at 6.3 PeV. In this instance the electrons might be overtaking the positrons in the laboratory frame, so that the  $Z^0$  is fast forward moving and the beam direction determined thereby.

The size of the region illuminated by such a beam from a distance of 1 kps (about 3000 light years,  $3 \times 10^{16}$  km) is about 3000 AU across. If we require a beam such that there would be at least 100 neutrinos per km<sup>2</sup> area, then the individual pulse would have to have around  $10^{26}$  neutrinos (here we use an opening angle in the  $Z$  decay of about  $M_Z/E_\nu$ ).

Needless to say, the numbers we cite are illustrative only as we clearly could not anticipate all possible scenarios. For instance, the ETI may be relatively nearby, either on an extrasolar planetary base or in a space station, waiting for us to build a suitable neutrino telescope.

#### 4. Energy costs

Accelerators are marvelously good at transforming electrical energy into beam energy, typically putting tens of percent of the wall-plug power into the beam. One can imagine a total energy transfer from the delivered power to neutrinos of perhaps 0.1%. In contrast, radio is better, by perhaps one or two orders of magnitude. Lasers are currently not very efficient, but their technology is still evolving rapidly. One may thus argue that the cost of making a neutrino beam is not prohibitive in comparison to photon beams. Also, the radio beams have the potential disadvantage of sidelobes, which could be a strongly negative factor if the security issue is real or perceived to be so.

At an energy cost of order  $10^{25}$  Joules per pulse (allowing for accelerator efficiency and the fact that the  $Z$  decays into neutrinos only 20% of the time, and of that only 1/6 will be electron–anti-neutrinos), this is a huge energy output. If the pulses were fired once per second, the accelerator power would be about 3% of the solar luminosity. In fact, taking into account the flat spectrum of

the neutrinos from  $Z$  decay after the boost, there is a further factor of  $m_Z/\Gamma_Z$ , which makes the required power about equal to the solar luminosity. This is clearly not a task we can imagine carrying out on any projection of our present technology.

However, we do not know the methods that may be available to advanced civilizations to make a neutrino (or any other) beam. We have direct evidence in the  $10^{20}$  eV cosmic rays, the gamma ray bursts (GRBs), the micro-Quasars, and the amazingly collimated jets from active galactic nuclei (AGN), so that we might suspect that we do not yet understand some fundamental issues on particle acceleration. For example, how does one get an earth mass accelerated to a gamma of 1000 in a distance of a few light seconds, as has been inferred for gamma ray burst jets or “cannonballs”? There is also the possibility mentioned earlier of employing “Dyson” stars. So, for present purposes, we shall assume that an ETI would find it affordable and worthwhile to expend such resources to communicate with our TES.

#### 5. Information encoding via pulse timing

What about encoding? Since we are talking about relatively rare events, it seems evident that the encoding information by relative timing of the neutrino pulses provides the only mechanism, much as the use of a simple Morse code in the early days of electromagnetic communication. Also, neutrinos are fermions and presumably encoding could only involve classical physics, rather than say some hypothetical analog of the laser.

Neutrino oscillations might permit some further encoding, but given the distances, oscillations are averaged out. For neutrinos coming from a distance near that to the galactic center, the solar oscillations will have made about a million cycles. If the beam energy were sharp to parts per million, then in fact one would have to worry about the phase of the cycle (earth could be in a null), but this seems not a problem. In any event if only electron anti-neutrinos are detected (as we are considering here), then no information can be encoded in neutrino flavor.

Thus there would be some interval between pulses, which we interpret as some number of time increments long, and that is the message. What would be the natural time increment? One possibility would be the lepton associated 0.3 ps lifetime of the tauon. This timing over a large detector is not presently practical, and would seem to be not possible in the foreseeable future. The muon lifetime of 2.2  $\mu$ s would be much easier and more practical. The minimum time interval detectable with present detectors is of the order of 1 ns, and may reach 100 ps in a few decades. With maximum resolution, if events were spaced apart by, say (arbitrarily) 2200 s on average, then this is  $10^9$  intervals per pulse, or equivalent to 30 bits, or an equivalent data rate of about 0.014 baud, not so bad for interstellar communications! If we assume transmission with, say, three repetitions then this would be 143 000 bits per year, quite a respectable amount of data.

Some thought should be given to how the ETI might encode data in a way which would be most simple to decode. For example, coarse level timing might encode for the simplest messages helping to establish the link and achieve synchronization, with finer and finer detail encoding more and more complex data.

Finally, at the risk of speculating beyond what would be warranted at present, we might try to guess the content of a message from an advanced civilization. We could ask what we might say if we were in a position to start transmitting. As suggested in another context [8], in light of the physicist’s well documented and almost irresistible urge to publish, an advanced civilization might just want to announce that it has figured out how the universe ticks. A concise summary would be the gauge algebras of the three non-gravitating interactions suitably coded.

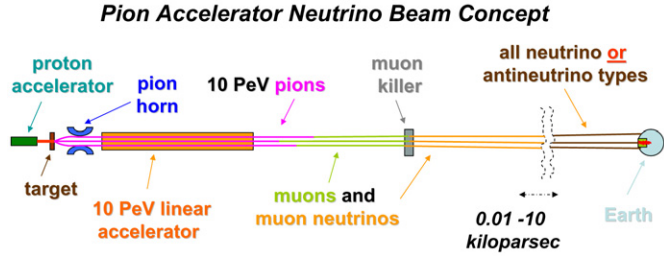


Fig. 2. Cartoon of muon neutrino production from a pion accelerator. Neutrinos mix and all flavors are detected, but only anti-neutrinos will have Glashow resonant events.

## 6. An alternative with neutrino superbeams

As this Letter was being drafted, a preprint appeared [3] which proposed that communication from nearby stars might be conducted with neutrino beams such as will be inherent in a muon collider. In present discussions of such, one would rapidly accelerate muons made from pion decays in the 1 GeV energy range (the pions made in collisions of a few megawatt proton beam of a few tens of GeV with a fixed target). These muons would then circulate in order to study high energy muon pair collisions. The muons decay and create a powerful (and even dangerous) neutrino beam. And, there has been much discussion of neutrino factories, using muons as discussed, but only keeping them in a race track (with long straight sides) shaped ring or a nearly triangular ring, with sides pointed at distant detector. Indeed such instruments seem to provide the path towards detailed measurements of neutrino mixing, and we think will be built in the foreseeable future.

We propose an alternative to this which seems to be even more interesting, as illustrated in the cartoon in Fig. 2. Our idea is to accelerate the charged pions before they decay to muons, and to take them to energies in the range discussed previously,  $\approx 30$  PeV, so that the decays would make neutrinos in the 6.3 PeV energy range. The decay distance for pions of this energy will be about 0.5 million km, or about the distance to the moon. The positively charged pions will decay into positive muons and muon neutrinos, and negative pions vice versa, with resulting anti-neutrinos. If one aims the beam at a relatively thin shield (rock) one will kill the muons (which radiate very copiously at this energy), but leave the neutrinos. Hence in selecting whether positive or negative pions are accelerated, one may choose neutrinos or anti-neutrinos as the beam.

In case of  $\pi^+$ , only  $\nu_\mu$ 's are produced and from  $\pi^-$  only  $\bar{\nu}_\mu$ 's are produced. As is well known [9] the averaged out oscillations, after a distance of about a few light days, convert these into a mixture of all three flavors in the proportion given by  $\nu_e : \nu_\mu : \nu_\tau = 4 : 7 : 7$ , but keeping the particle/antiparticle nature as is. Hence, since it is a matter of sign selection in the accelerator one can switch the neutrino beam between particles and antiparticles, switching on and off the Glashow resonance. There will be a constant signal from either beam due to the other charged and neutrino current reactions. Thus there will be different signatures for neutrinos and anti-neutrinos, and one may encode information in the nature of each pulse, without regard to timing. In addition, timing can be employed as well, as discussed earlier for the resonant  $Z^0$  scheme, and we can substantially boost the data transmission rate.

A strong further attraction of the pion scheme is that the maximum neutrino angle relative to the pion is  $(m_\pi^2 - m_\mu^2)/2m_\pi/E_\nu$  so the beam is much narrower than the  $Z^0$  beam and the target area is smaller by about a factor of about  $10^7$ . All transmitter powers involved are dramatically reduced so that we would be considering a total beam energy requirement per pulse of order one

gigajoule. This is on the order of the energy per pulse which is being discussed for near future controlled fusion reactions on Earth. Given such "modest" power levels, one may imagine transmitting at rates higher than hypothesized for the resonant  $Z^0$  method, perhaps one per second, as is easily foreseeable with present technology (a gigawatt of power, less than many present nuclear power stations).

The penalty for the tight beam however is that the ETI must know the precise planet they are targeting and know its ephemeris, since the 10 million km beam spread (from 1 kpc) is less than 0.01 AU. If they have surveyed the stellar systems and singled out earth, then this would not seem a barrier as they would of necessity have determined the orbital parameters, and extrapolation of the earth's orbit over a few millenia should pose no problem.

The only thing we do not yet readily foresee in this scheme is how to accelerate the pions to this high energy (30 PeV). Yet, a linear accelerator (in space) with a gradient of 100 GeV/m (already achieved for short distances in the laboratory) would require a length of 1000 km, which seems not wildly implausible for a future civilization. Also, while aiming with sufficient precision would certainly pose problems for us at present (at the level of 0.07 milli-arc-seconds), such a scale would be needed by the ETI to optically resolve the earth in any event.

## 7. Concluding remarks

We have outlined a method for intragalactic communication via directed 6.3 PeV beams of electron–anti-neutrinos, and other neutrinos. Such beams can be created with reasonable energy efficiency by a civilization without a long stretch from the technology we now possess. Detection of such a beam, possible given a detecting civilization with our present level of neutrino detectors (cubic kilometer scale), would be evidently due to ETI with only a few events detected since there is no known mechanism for making neutrinos at only this energy range. Plus, having a few as two neutrinos arrive from precisely the same direction would be very unlikely unless accompanied by a huge burst of radiation in other bands. Data would accumulate at a rate plausibly about 1 Hz equivalent bandwidth and decoding the pattern would take perhaps one year. This would amount to transmission of 1000 pages of material per year, a tremendous amount of information. Given that the transmitting entity would have to know about the earth's (and other targets') ephemeris and possibly even day cycle, their transmission might be set to repeat several times daily and again on a longer cycle. Given that the ETI have no a priori knowledge of when observations will begin, and cannot get feedback for millenia afterward, multiple transmissions would be necessary, but perhaps only once in a few years, as perhaps they would illuminate other systems alternately and if our picture of the device is at all accurate, redirecting the accelerator would require some time.

No special action is required on our part, since if this speculative hypothesis should be correct, we will soon discover such signatures, but perhaps such will not arrive for some time. This adds motivation to keep all neutrino telescopes operating for long timescales, such as the watch for supernovae in our galaxy and unpredictable burst events of all types. We humans should certainly think about and continue to explore other means for such communications, but to us neutrinos seem to provide some special opportunities.

## Acknowledgements

This work was supported in part by the U.S.D.O.E. under grant DE-FG02-04ER41291 at University of Hawaii, and by the N.S.F. un-

der grant 04-56556 at University of California at Santa Barbara. Two of us (S.P. and A.Z.) would also like to thank Xiao-Gang He, Pauchy Hwang and their colleagues at the NTU for their hospitality and the stimulating atmosphere where this work was begun. We also thank Xerxes Tata for useful discussions.

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